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OFRI · IRFO

Modelling the Future Forest: Establishing a Sound Basis for Climate Change Research

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Introduction

Growing plants in a range of environments is a highly useful way of understanding how trees may adapt to climate change. Climatologists are predicting rapid and extreme changes in climate on a global scale and climatic conditions anticipated for the latter part of this century can be mimicked using controlled environment facilities. One of the most sophisticated collections of controlled environment facilities in Canada exists at the Ministry of Natural Resources' (MNR) Ontario Forest Research Institute (OFRI) in Sault Ste. Marie, Ontario. This paper describes how these facilities can contribute to ongoing climate change research efforts using examples of past OFRI research.

Background

The release of greenhouse gases to the atmosphere, primarily from burning fossil fuels, is projected to increase global surface air temperature by at least 1°C during the 21st century (IPCC 2001). Temperature changes are expected to be greater at night than during the day and in winter as compared to summer. Elevated temperatures will be associated with increased global precipitation. However, changes in climate will vary regionally, with temperatures expected to increase more at higher latitudes. Precipitation will also vary regionally, with some areas experiencing decreased rain and or snowfall and others receiving more. The inability of species to acclimate to changes in temperature and moisture availability may result in episodes of regional forest decline and fundamental alterations to forest ecosystems (Parker et al. 2000). Changes in climate along with anticipated increases in natural disturbances will likely initiate the migration and re-assembly of plant species into forests with no modern analogue.

The atmospheric concentration of the most plentiful "greenhouse gas", CO_2, is expected to double from pre-industrial levels in as little as 50 years. At the whole plant scale, elevated CO_2 may strongly affect forest ecosystems through effects on photosynthesis. Variation in response to elevated CO_2 may also change the competitiveness among species. This in turn would affect forest succession patterns and result in changes in species diversity. At the forest ecosystem level, a CO_2-enriched atmosphere may change net primary productivity, net ecosystem productivity, and carbon and nutrient cycling.

Silvicultural intervention can reduce the negative effects of climate change on the productivity, health, and values of Ontario's forests. However, the development of forest management practices to help forests adapt requires a better understanding of the effects of climate on forests in a CO_2-enriched atmosphere (Colombo and Parker 1999). Flooding forest plots with CO_2 (known as free air CO_2 enrichment, or FACE) or heating forest plots (free air temperature enhancement, or FATE), provide the most realistic projections of the complex effects of CO_2 and temperature on forest ecosystems. Controlled environment experiments continue to complement this work and contribute to efforts to model the future forest.

The long-term nature of forestry requires that resource managers consider the effects of projected climate change on forests. Artificial regeneration is a particularly critical decision. Species and seed sources can be chosen based on their adaptation as climate becomes warmer and drier or wetter and the optimum climate for these species shifts. Clearly, the identification of provenances of ecologically and commercially valuable tree species that are adapted to a variety of site conditions is an important area of climate change research. As well, CO_2-altered competitiveness of plant species may affect the establishment of new stands of trees.

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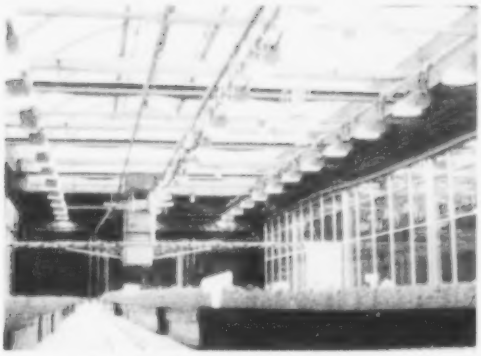
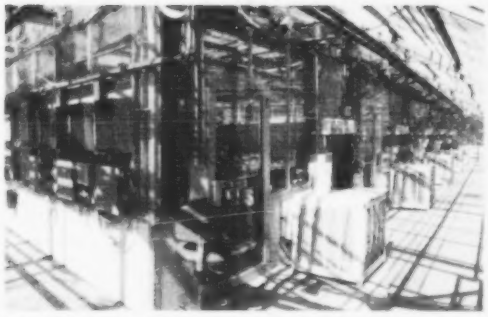
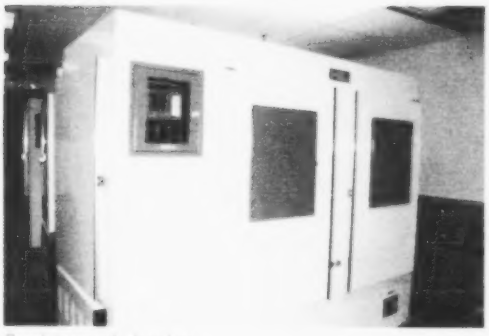


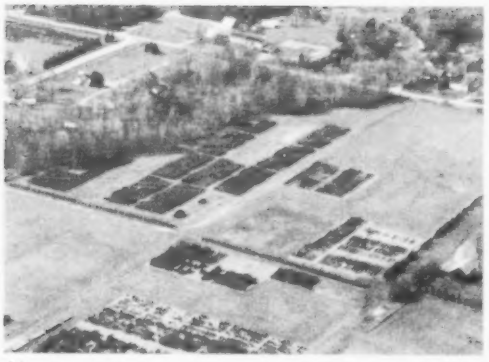
Gutter-connected greenhouses



Glass cubicle greenhouses



Reach-in growth chambers



Arboretum

Understanding how plants respond to elevated CO_2 in different climates can be predicted by growing plants in controlled environment facilities. From this, non-traditional tree species or particular genotypes of existing species may be selected and silvicultural treatments developed to establish forests that are better suited to growing in the latter half of this century. The research facilities at OFRI (described below) can be used to develop information on adaptation of species to develop more effective silvicultural treatments for coping with climate change.

OFRI's climate change research facilities

OFRI is housed in a 9,000 m² facility with a variety of laboratories, greenhouses and controlled environment chambers. Fully equipped laboratories are available for analyses of (1) inorganic constituents of plant tissues, soil and water, (2) plant biochemistry, (3) plant chlorophyll fluorescence, (4) forest pathology, (5) plant anatomy, and (6) plant stress physiology. As well, the institute maintains two facilities for field research. The nearby OFRI arboretum is a largely non-forested, 95 ha site available for field research (e.g., Bell et al. 2000). This area has a variety of soil conditions and provides a convenient location for short-term studies of, for example, stock quality, tree improvement, and genecology. Elevated sand beds with heat lamps covered by rain shelters have been constructed that allow the effects of moisture stress and high temperatures on forest plants to be examined. The Swan Lake Forest Research Reserve, a 2,000 ha forested area located in Algonquin Provincial Park, supports research of Great Lakes-St. Lawrence forest ecosystems ecology and silviculture (e.g., Cole et al. 1999).

OFRI has three general types of computer-automated greenhouses that differ in the degree of environmental control capability.

- Three, 300 m² glass gutter-connected greenhouses are available for comparatively large experiments. These greenhouses feature CO_2 enrichment, automatic irrigation and fertilization systems, overhead and underbench heating, multiple-stage cooling, and high-pressure fog systems. Light is provided by natural sunlight and high-pressure sodium vapour lighting, with photoperiod controlled by blackout curtains. Light intensity can also be controlled using an automated shadecloth system.
- Ten glass cubicle greenhouses are available for smaller elevated CO_2 experiments. Each cubicle has a growing area of 1.2 m² and can be individually programmed to control temperature and photoperiod.
- A quonset-style, double-layered polyethylene greenhouse allows researchers to replicate growth conditions typical of Ontario's forest tree seedling production facilities. It has a growing area of about 140 m² and the photoperiod and temperature control features of the glass greenhouses.

Better control of the growth environment is possible using the 12 walk-in growth rooms and 24 reach-in growth chambers located at OFRI. These facilities can produce a range of temperatures (Walk-in: -30 to 40°C; Reach-in: 4 to 45°C) and can create projected future diurnal and seasonal temperature regimes. Six, specially designed reach-in growth chambers that can provide elevated CO_2 conditions allow researchers to simulate future climatic and atmospheric environments.

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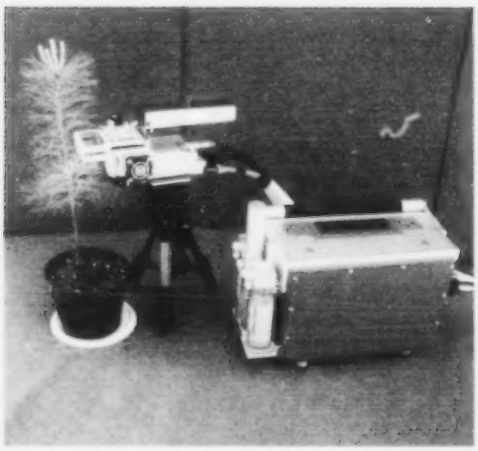

LI-6400 photosynthesis meter

Steady-state porometer

Pressure chamber

Laboratories and equipment

The tree and plant stress assessment laboratory has a variety of equipment to examine physiological processes in simulated future climates created by OFRI's growth facilities. Photosynthesis is a crucial process in plants as it provides the energy for all growth and maintenance processes. The exchange of CO_2 between leaves and the atmosphere reveals how rapidly leaves are absorbing CO_2. All other factors being equal, the faster the rate of CO_2 absorption, the greater the rate of photosynthesis. The institute has four portable photosynthesis measurement systems, including a LI-6400 photosynthesis meter (LiCor, Lincoln, NE). This instrument for laboratory or field measurement of photosynthesis allows the user to control the leaf environment, so that adaptations of photosynthesis to varying CO_2, humidity, temperature and light conditions can be determined. The institute also is equipped with three portable pulse-amplitude-modulation fluorometers (PAM-2000, Walz, Effeltrich, Germany). The fluorometer measures the photochemical processes involved in photosynthesis and is a good proxy for direct photosynthesis measurements (Mohammed et al. 1995). The advantage of the fluorometer is that the maximum potential of the leaf can be measured, while photosynthesis measurements based on CO_2 exchange can be affected by other plant factors, such as the degree of stomatal opening of the leaves. Used together, the photosynthesis meter and fluorometer can provide a comprehensive examination of climate change effects on many fundamental photosynthetic processes (Mohammed and Parker 1999, Parker and Mohammed 2000).

Increased temperatures in combination with altered precipitation will influence soil moisture, perhaps exposing plants to greater or lesser levels of water stress. Even where growing season precipitation is unaffected, increased temperature will reduce soil water levels because of higher evaporation and transpiration rates. Where precipitation is reduced, periods of drought and severe plant water stress may develop, reducing the growth and competitiveness of non-adapted plants. Transpiration and stomatal conductance are important aspects of plant gas exchange that determine how effectively a plant regulates leaf water loss during photosynthesis. OFRI is equipped with a steady-state porometer (LI-1600, LiCor, Lincoln, NE), an instrument that measures water vapour exchange between leaves and the atmosphere, and has several pressure chambers (PMS Instruments Co., Corvallis, OR), which measure the degree of water stress that plants are under. This equipment can be used to determine the water status of different plant tissues (leaves, shoots, roots) which is important for studying plant adaptations to drought (Colombo and Teng 1992, Parker and Colombo 1995).

Plant growth and survival under low and high temperature stresses that may occur with climate change can also be evaluated using facilities at OFRI. Warmer winter temperatures may result in earlier budbreak, but this may increase the risk of damage from late spring frosts (Colombo 1998). Environmental and genetic effects on frost hardiness can be evaluated using as many as nine freezing chambers with the capacity to produce temperatures as low as −40°C. Future climate change effects on high temperature adaptation can also be evaluated using these chambers or using a hot water immersion technique (Colombo and Timmer 1992). Assessment of low and high temperature adaptation of species, nursery stocktypes, and genotypes will be critical to the operational production of a variety of planting materials that are suited to the current and future climates of reforestation sites.

Conclusion

Climate change is increasing the uncertainty about how best to manage forests. To reduce this uncertainty, more and better information is needed about how to sustain existing ecosystems and how commercially and ecologically important forest plants will behave under changing temperature, precipitation, and atmospheric CO_2 conditions. MNR's Ontario Forest Research Institute contains among the most sophisticated climate simulation facilities in Canada. These facilities can be used to address questions about the effect of climate change on forest ecosystems and their management. For example, plants can be exposed to future climate scenarios in a controlled way to aid in development of effective approaches to forest adaptation. The equipment available for measurement of plant physiological variables will allow researchers to predict how future climate may affect plant growth and physiological processes. Associated laboratory facilities provide the capacity to determine the influence of climatic perturbations on plant nutrient relations, plant biochemistry, and plant anatomy.

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